SNEWS: A Neutrino Early Warning System for Galactic SN II

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Abstract. The detection of neutrinos from SN1987A confirmed the core-collapse nature of SN II, but the neutrinos were not noticed until after the optical discovery. The current generation of neutrino experiments are both much larger and actively looking for SN neutrinos in real time. Since neutrinos escape a new SN promptly while the first photons are not produced until the photospheric shock breakout hours later, these experiments can provide an early warning of a coming galactic SN II. A coincidence network between neutrino experiments has been established to minimize response time, eliminate experimental false alarms, and possibly provide some pointing to the impending event from neutrino wave-front timing.

INTRODUCTION

In a supernova (SN) driven by the gravitational collapse of a massive stellar core into a neutron star (*e.g.* Type II or Type Ib SNe), the resulting huge pulse of neutrinos escapes the star promptly after the collapse (for a detailed review and discussion of SN neutrinos, see [1]). In the case of the nearby SN1987A, these neutrinos were observed by the Kamiokande [2] and IMB [3] neutrino detectors in offline analyses performed after the optical discovery of the SN. Although the neutrinos escape the star promptly, photons do not get out until the shock wave travels from the core through the stellar envelope and breaks out of the stellar photosphere – hours later, depending upon the size of the envelope (ref. [4] contains a simple model of this delay). Thus, if the neutrinos could be detected in real-time, they would provide advance warning of the coming photons from the SN. Such a warning would allow preparation of observations over the whole electromagnetic spectrum, maximizing the information gathered during the previously unobserved first few hours of light from a new SN.

The <u>S</u>uper<u>n</u>ova <u>E</u>arly <u>W</u>arning <u>S</u>ystem (SNEWS) [5] is a coincidence trigger between the world's neutrino telescopes. While the individual neutrino detectors all have near real-time SN monitors which are sensitive to SNe in the Milky Way galaxy and its satellites (*e.g.* [6–8]), those monitors could be fooled by instrumental effects. To avoid releasing such a false alarm, any single experiment would want its SN monitor output to be carefully scrutinized by a human. Unfortunately, the time scale on which humans operate is of the same order as the lead time gained by the neutrinos over the photons, which would waste much of the advance notice. Those extra hours would be better spent by observers preparing to observe the impending photons. However, the likelihood of two independent experiments experiencing a false alarm in coincidence is very small, therefore an automated alert can be issued with confidence. If each input experiment has a false alarm rate of < 1/week, the false coincidence rate will be $\ll 1$/century. Thus, the SNEWS network can eliminate the need for active human supervision and provide an alert to the astronomical community as promptly as possible by providing an automated alarm when multiple experiments simultaneously see a SN-like neutrino signal.

THE SNEWS NETWORK

There are a number of experiments capable of detecting neutrinos from a galactic SN (Tab. 1) either active now or coming online within the next few years. Experiments participating in the SNEWS network send a standard UDP packet via the internet to a remote server when their local automated SN monitor detects a SN-like signal in their detector. This remote server forms a blind coincidence trigger between incoming alert packets and issues an alarm to interested observers should it record multiple experimental SN triggers time-stamped within 10 seconds (in UTC) of each other.

When the SNEWS server sees such a coincidence between experiments, it will issue an alert via email to all interested parties. Email to pager gateways will provide the fastest initial notification. Currently the MACRO, Super-Kamiokande, and LVD experiments are providing automated inputs to this coincidence trigger. It is anticipated that the SNO and AMANDA experiments will begin providing inputs early in the year 2000. To verify the prediction of a vanishingly small rate of false alarms, the coincidence server is presently running in a test mode that would not send out an automated alarm. Since no false coincidences have occurred, SNEWS will be switched over to its final, fully automated configuration in the year 2000.

WHAT INFORMATION CAN SNEWS PROVIDE?

The single most important information provided by SNEWS would be simply the fact that within hours, a nearby SN will soon be visible. If nothing else, this alarm will allow observers get set up so as to be able to start observing as soon as more information becomes available.

Detector	Type	Mass (kton)	Location	# events @10 kpc	Status
Super-K	water Cherenkov	32	Japan	4400	**signaling SNEWS since May 1998**
MACRO	scint.	0.6	Italy	150	**signaling SNEWS since March 1998**
LVD	scint.	0.7	Italy	170	**signaling SNEWS since Feb. 1999**
SNO	H_2O, D_2O	1.7 1	Canada	350 430	running
AMANDA	long string	$M_{eff} \sim$ 2/pmt	Antarctica	N/A	running
Baksan	scint.	0.33	Russia	70	running
Borexino	scint.	1.3	Italy	$\sim$200	2000
Kamland	scint.	1	Japan	300	2001
OMNIS	high Z	10 kT Fe, 4 kT-Pb	USA	2000	2000+
LAND	high Z	1	Canada	450	2000+
Icanoe	liquid argon	9	Italy		2000+

TABLE 1. Current and near-future neutrino detectors capable of detecting the neutrino signal from a galactic core-collapse SN. **Bold** entries are currently providing input to the SNEWS network.

Naturally more information would be desirable, particularly that which tells observers where to look. There are two methods which could provide pointing information from the neutrino signal. The first takes advantage of the directionality of some neutrino interaction channels in individual detectors, most notably electron scattering ($\nu_x + e^- \rightarrow \nu_x + e^-$) in the large water Cherenkov detectors. For a SN at 10 kpc, it is estimated that Super-K could point to a $\sim 5^\circ$ cone on the sky, and SNO a $\sim 20^\circ$ cone [9]. While hardly precise by photon astronomy standards, these solid angles are easily covered by large field of view instruments. This directional information is not a product of the SNEWS network but that of the individual experiments' analyses, but SNEWS could play an important role in disseminating and correlating such information as it becomes available.

The second pointing method is unique to SNEWS. The precise timing of the neutrino wavefront arrival at the different detectors' widely separated locations on the earth could be used to reconstruct where the neutrinos were coming from. Unfortunately, a detailed analysis [9] of the statistics available to the current detectors suggests that this "triangulation" approach would be substantially less precise than the $\nu + e$ scattering, being mostly valuable as a confirmation rather than as a position refinement – but this itself is both a helpful and important cross-check.

PLANS FOR USE OF AN EARLY WARNING

Should a core-collapse SN occur in the range of the neutrino detectors (within the Milky Way galaxy or its satellites), an alert would be issued hours before light is produced by the new SN. This short detection range ensures that any SN signal triggering SNEWS will be very nearby and thus a potential scientific bonanza. Conversely, this short range translates to a probe of a very limited volume, making for a low observable SN rate [10] of the order of several SNe per century. In order to make the most of this once in a lifetime opportunity, good plans should be developed in advance, to be put into action when a SN does occur.

Two examples of such planning are currently in place. The first is from the editors of *Sky & Telescope* magazine, who are preparing to both provide a means to disseminate the alarm information to the amateur astronomer community, and to manage the resulting flow of observations such an alarm would generate [11]. The celebrated accidental observations of SN1987A by the amateur astronomer Albert Jones were instrumental in studying the early stages of this important event. An organized effort by the many similarly skilled observers available would not only provide many more valuable early observations, but also aid greatly in precisely locating the new SN, given both the wide angle instruments commonly used by amateurs and their sheer numbers, experience with the sky, and enthusiasm.

The second example is a Hubble Space Telescope Target of Opportunity proposal from J. Bahcall *et al* [12]. Given the long response time of the HST and the precise positional information needed to point it, these observations would not occur until days after the initial alarm. However, the HST is the only facility available to take the high resolution UV spectra needed to understand the nearby environment of the new SN, and having the detailed observation plans on file and ready to be used would not only save time but provide better results when they are needed.

Any astronomer who might want to observe such an important event is encouraged to make similar plans. Plans and preparations now not only will make good observations easier when the exciting but hectic time comes to observe a galactic SN, but there are undoubtably many good ideas as yet unborn. Some good thinking now in the idle years while waiting for such an event will allow these ideas to be fleshed out and properly put into practice when it counts.

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